SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

*RHYTHMS AND GEOLOGIC TIME.**

CUSTOM dictates that in complying with the rule of the Association I shall address you on some subject of a scientific character. But before doing so I may be permitted to pay my personal tribute to the honored and cherished leader of whose loss we are so keenly sensible on this occasion. His kindly personality, the charm which his earnestness and sincerity gave to his conversation, the range of his accomplishment, are inviting themes; but it is perhaps more fitting that I touch this evening on his character as a representative president of this body. The Association holds a peculiar position among our scientific organizations of national or continental extent. Instead of narrowing its meetings by limitations of subject matter or membership, it cultivates the entire field of research and invites the interest and co-operation of all. It is thus not only the integrating body for professional investigators, but the bond of union between these and the great group of cultured men and women—the group from whose ranks the professional guild is recruited, through whom the scientific spirit is chiefly propagated, and through whose interest scientific research receives its financial support. Its aims and form of organization recognize, what pure science

* Read to the American Association for the Advancement of Science at New York, June 26, 1900, as the address of the retiring President.

does not always itself recognize, that pure science is fundamentally the creature and servant of the material needs of mankind, and it thus stands for what might be called the human side of science. Edward Orton, throughout his career as teacher and investigator, was conspicuous for his attention to the human side of science. His most abstract work was consciously for the benefit of the community, and he ever sought opportunity to make its results directly available. In promoting the interests of the people of his adopted state he incidentally accomplished much for a larger community by helping it to an appreciation of the essential beneficence of the scientific study of nature and man. As an individual he was a diligent and successful laborer in the field which the Association cultivates, and when the Association selected him as its standard bearer it made choice of one who was peculiarly its representative.

The subject to which I shall invite your attention this evening is by no means novel, but might better be called perennial or recurrent; for the problem of our earth's age seems to bear repeated solution without loss of vigor or prestige. It has been a marked favorite, moreover, with presidents and vice-presidents, retiring or otherwise, when called upon to address assemblies whose fields of scientific interest are somewhat diverse—for the reason, I imagine, that while the specialist claims the problem as his peculiar theme of study he feels that other denizens of the planet in question may not lack interest in the early lore of their estate.

The difficulty of the problem inheres in the fact that it not only transcends direct observation but demands the extrapolation or extension of familiar physical laws and processes far beyond the ordinary range of qualifying conditions. From whatever side it is approached the way must be paved by postulates, and the resulting views are so discrepant that impartial onlookers have come to be suspicious of these convenient and inviting stepping stones.

That vain expectation may not be aroused I admit at the outset that I have not solved the problem and shall submit to you no estimates. My immediate interest is in the preliminary question of the available methods of approach, and it leads to the consideration of the ways, or the classes of ways, in which the measurement of time has been accomplished or attempted.

Of the artificial devices employed in practical horology there are two so venerable that their origins are lost in the obscurity of legendary myth. These are the clepsydra and the taper. In the clepsydra advantage is taken of the approximately uniform rate at which water escapes through a small orifice, and time is measured by gaging the loss of water from a discharging vessel or the gain in a receiving vessel. The hour glass is one of its later forms, in which sand takes the place of water. The taper depends for its value as a time piece on the approximate uniformity of combustion when the area of fuel exposed to the air is definitely regulated. It survives chiefly in the prayer stick and safety fuse, but the graduated candle is perhaps still used to regulate monastic vigils.

The pendulum, a comparatively modern invention, excelling the clepsydra and taper in precision, has altogether supplanted them as the servant of civilization. Its accuracy results from the remarkable property that the period in which it completes an oscillation is almost exactly the same, whatever the arc through which it swings. It regulates the movements not only of our clocks, watches and chronometers, but of barographs, thermographs and a great variety of other machines for recording events and changes in their proper order and relation in respect to time.

I must mention also a special apparatus invented by astronomers and called a chronograph. It consists ordinarily of a revolving drum about which a paper is wrapped and against which rests a pen. As the drum turns the pen draws a line on the paper. Through an electric circuit the pen is brought under the influence of a pendulum in such a way that at the middle of each swing of the pendulum the pen is deflected, making a mark at right angles to the straight line. The series of marks thus drawn constitutes a time scale. The electric arrangements are so made that the pen will also be disturbed in consequence of some independent event, such as the firing of a gun or the transit of a star; and the mark caused by such disturbance, being automatically platted on the time scale, records the time of the event.

No attempt has been made to characterize these various time pieces with fullness, because they are already well known to most of those present, and, in fact, the chief motive for giving them separate mention is that they may serve as the basis of a classification. In the use of the clepsydra and taper, time is measured in terms of a continuous movement or process; in the use of the pendulum time is measured in terms of a movement which is periodically reversed. The classification embodies the fundamental distinction between continuous motion and rhythmic motion.

Passing now from the artificial to the natural measures of time we find that they are all rhythmic. It is true that the spinning of the earth on its axis is in itself a continuous motion, but it would yield no time measure if the earth were alone in space, and so soon as the motion is considered in relation to some other celestial body it becomes rhythmic. As viewed from, or compared with, a fixed star the period of its rhythm is the sidereal day; compared with the sun it is the solar day, nearly four minutes longer; and compared with the moon it is the lunar day, still longer by 49 minutes. As the sun supplies the energy for most of the physical and all the vital processes of the earth's surface, the rhythm of the solar day is impressed in multitudinous ways on man and his environment, and he makes it his primary or standard unit of time. He has arbitrarily divided it into hours, minutes and seconds, and in terms of these units he says that the length of the sidereal day is a little more than 23 hours, 56 minutes and 4 seconds, and the average length of the lunar day is a little less than 24 hours and 49 minutes. The lunar day finds expression in the tides and is of moment to maritime folk, but the sidereal is known only to astronomers.

Next in the series of our natural time units is the month, or the rhythmic period of the moon regarded as a luminary. By our savage ancestors, who credited the moon with powers of great importance to themselves, much use was made of this unit, but as progress in knowledge has shown that the influence of the satellite had been vastly overrated, less and less attention has been paid to the returning crescent, and it is only in ecclesiastic calendars that the chronology of civilization now recognizes the natural month. Its shadow survives, without the substance, in the calendar month; and the week possibly represents an early attempt to subdivide it.

In passing to our third natural unit, the year, we again encounter solar influence, and find the rhythm of the earth's orbit echoed and reechoed in innumerable physical and vital vibrations. As the attitude of the earth's axis inclines one hemisphere toward the sun for part of the year and the other hemisphere for the remainder, the whole complex drama of climate is annually enacted, and the sequence of man's activities is made to assume an annual rhythm. The year is second only to the day as a ter-

restrial unit of duration; and as the day is man's standard for the minute division of time, so the year is his standard for larger divisions, and the decade, the century and the millenium are its multiples.

But the rhythms of day and night, of summer and winter, are not the only tides in the affairs of men. At birth we are small, weak and dependent, we grow larger and stronger, we become mature and independent, and then by reproducing our kind we complete the cycle, which begins again with our children. The cycle of human life is the *generation*, a time unit of somewhat indefinite length and varying in phase from family to family, but holding a place, nevertheless, in human chronology.

Still less definite is the rhythm of hereditary rulership, progressing from vigor through luxury to degeneracy, and closing its cycle in usurpation; yet it makes an epoch in the life of a nation or empire, and so the *dynasty* is one of the units of the historian.

The generation and the dynasty are of waning importance in human chronology, and they can claim no connection with the problem of geologic time; but here again I have turned aside for a moment in order to illustrate a principle of classification. The daily rhythm of waking and sleeping, of activity and rest, does not originate with man but is imposed on him by the rhythm of light and darkness, and that in turn springs from the turning of the earth in relation to the shining sun. The yearly rhythm of sowing and harvesting, of the fan and the furnace, does not originate with man but is imposed on him by the rhythm of the seasons, and that in turn springs from certain motions of the earth in relation to the glowing sun. But the rhythm of the generation and the rhythm of the dynasty have origin in the nature of man himself. The rhythms of human chronology may thus be grouped according to source in two classes, the *imposed* and the *original;* and the same distinction holds for other rhythms. The lunar day is an original rhythm of the earth as seen from the moon; the ground swell is an original rhythm of the ocean; but the tide is an imposed rhythm of the ocean, being derived from the lunar day. The swing of the pendulum is an original rhythm, but the regular excursion of the chronograph pen, being caused by the swing of the pendulum, is an imposed rhythm.

In giving brief consideration to each of the more important ways by which the problem of the earth's age has been approached, I shall mention first those which follow the action of some continuous process, and afterward those which depend on the recognition of rhythms.

The earliest computations of geologic time, as well as the majority of all such computations, have followed the line of the most familiar and fundamental of geologic processes. All through the ages the rains, the rivers and the waves have been eating away the land, and the product of their gnawing has been received by the sea and spread out in layers of sediment. These layers have been hardened into rocky strata, and from time to time portions have been upraised and made part of the land. The record they contain makes the chief part of geologic history, and the groups into which they are divided correspond to the ages and periods of that history. In order to make use of these old sediments as measures of time it is necessary to know either their thickness or their volume, and also the rate at which they were laid down. As the actual process of sedimentation is concealed from view, advantage is taken of the fact that the whole quantity deposited in a year is exactly equalled by the whole quantity washed from the land in the same time, and measurements and estimates are made of the amounts brought to the sea by

rivers and torn from the cliffs of the shore by waves. After an estimate has been obtained of the total annual sedimentation at the present time, it is necessary to assume either that the average rate in past ages has been the same or that it has differed in some definite way.

At this point the course of procedure divides. The computer may consider the aggregate amount of the sedimentary rocks, irrespective of their subdivisions, or he may consider the thicknesses of the various groups as exhibited in different localities. If he views the rocks collectively, as a total to be divided by the annual increment, his estimate of the total is founded primarily on direct measurements made at many places on the continents, but to the result of such measurements he must add a postulated amount for the rocks concealed by the ocean, and another postulated amount for the material which has been eroded from the land and deposited in the sea more than once.

If, on the other hand, he views each group of rocks by itself, and takes account of its thickness at some locality where it is well displayed, he must acquire in some way definite conceptions of the rates at which its component layers of sand, clay and limy mud were accumulated, or else he must postulate that its average rate of accretion bore some definite ratio to the present average rate of sedimentation for the whole ocean. This course is, on the whole, more difficult than the other, but it has yielded certain preliminary factors in which considerable confidence is felt. Whatever may have been the absolute rate of rock building in each locality, it is believed that a group of strata which exhibits great thickness in many places must represent more time than a group of similar strata which is everywhere thin, and that clays and marls, settling in quiet waters are likely to represent, foot for foot, greater amounts of time than the coarser sediments gathered by strong currents; and studying the formations with regard to both thickness and texture, geologists have made out what are called *time ratios*,—series of numbers expressing the relative lengths of the different ages, periods and epochs. Such estimates of ratios, when made by different persons, are found to vary much less than do the estimates of absolute time, and they will serve an excellent purpose whenever a satisfactory determination shall have been made of the duration of any one period.

Reade has varied the sedimentary method by restricting attention to the limestones, which have the peculiarity that their material is carried from the land in solution; and it is a point in favor of this procedure that the dissolved burdens of rivers are more easily measured than their burdens of clay and sand.

An independent system of time ratios has been founded on the principle of the evolution of life. Not all formations are equally supplied with fossils, but some of them contain voluminous records of contemporary life; and when account is taken of the amount of change from each full record to the next, the steps of the series are found to be of unequal magnitude. Though there is no method of precisely measuring the steps, even in a comparative way, it has yet been found possible to make approximate estimates, and these in the main lend support to the time ratios founded on sedimentation. They bring aid also at a point where the sedimentary data are weak, for the earliest formations are hard to classify and measure. It is true that these same formations are almost barren of fossils, but biologic inference does not therefore stop. The oldest known fauna, the Eocambrian, does not represent the beginnings of life, but a well advanced stage, characterized by development along many divergent lines; and by comparing Eocambrian life with existing life the paleontolo-

gist is able to make an estimate of the relative progress in evolution before and after the Eocambrian epoch. The only absolute blank left by the time ratios pertains to an azoic age which may have intervened between the development of a habitable earth crust and the actual beginning of life.

Erosion and deposition have been used also, in a variety of ways, to compute the length of very recent geologic epochs. Thus, from the accumulation of sand in beaches Andrews estimated the age of Lake Michigan, and Upham the age of the glacial lake Agassiz; and from the erosion of the Niagara gorge the age of the river flowing through it has been estimated. But while these discussions have yielded conceptions of the nature of geologic time, and have served to illustrate the extreme complexity of the conditions which affect its measurement, they have accomplished little toward the determination of the length of a geologic period; for they have pertained only to a small fraction of what geologists call a period, and that fraction was of a somewhat abnormal character.

Wholly independent avenues of approach are opened by the study of processes pertaining to the earth as a planet, and with these the name of Kelvin is prominently associated.

As the rotation of the earth causes the tides, and as the tides expend energy, the tides must act as a brake, checking the speed of rotation. Therefore the earth has in the past spun faster than now, and its rate of spinning at any remote point of time may be computed. Assuming that the whole globe is solid and rigid, and that the geologic record could not begin until that condition had been attained, there could not have been great checking of rotation since consolidation. For if there had been, it would have resulted in the gathering of the oceans about the poles and the baring of the land near the equator, a condition very different from what actually obtains. This line of reasoning yields an obscure outer limit to the age of the earth.

On the assumption that the globe lacks something of perfect rigidity, G. H. Darwin has traced back the history of the earth and the moon to an epoch when the two bodies were united, their separation having been followed by the gradual enlargement of the moon's orbit and the gradual retardation of the earth's rotation; and this line of inquiry has also yielded an obscure outer limit to the antiquity of the earth as a habitable globe.

One of the most elaborate of all the computations starts with the assumption that at an initial epoch, when the outer part of the earth was consolidated from a liquid condition, the whole body of the planet had approximately the same temperature; and that as the surface afterward cooled by outward radiation there was a flow of heat to the surface by conduction from below. The rate of this flow has diminished from that epoch to the present time according to a definite law, and the present rate, being known from observation, affords a measure of the age of the crust. The strength of this computation lies in its definiteness and the simplicity of its data; its weakness in the fact that it postulates a knowledge of certain properties of rock—namely, its fusibility, conductivity and viscosity—when subjected to pressures and temperatures far greater than have ever been investigated experimentally.

A parallel line of discussion pertains to the sun. Great as is the quantity of heat which that incandescent globe yields to the earth, it is but a minute fraction of the whole amount with which it continually parts, for its radiation is equal in all directions, and the earth is but a speck in the solar sky. On the assumption that this immense loss of heat is accompanied by a corresponding loss of volume, the sun is

shrinking at a definite rate, and a computation based on this rate has told how many millions of years ago the sun's diameter should have been equal to the present diameter of the earth's orbit. Manifestly the earth can not have been ready for habitation before the passage of that epoch, and so the computation yields a superior limit to the extent of geologic time.

Before passing to the next division of the subject—the computations based on rhythms—a few words may be given to the results which have been obtained from the study of continuous processes. Realizing that your patience may have been strained by the kaleidoscopic character of the rapid review which has seemed unavoidable, I shall spare you the recitation of numerical details and merely state in general terms that the geologists, or those who have reasoned from the rocks and fossils, have deduced values for the earth's age very much larger than have been obtained by the physicists, or those who have reasoned from earth cooling, sun cooling and tidal friction. In order to express their results in millions of years the geologists must employ from 3 to 5 digits, while the physicists need but 1 or 2. When these enormous discrepancies were first realized it was seen that serious errors must exist in some of the observational data or else in some of the theories employed; and geologists undertook with zeal the revision of their computations, making as earnest an effort for reconciliation as has been made a generation earlier to adjust the elements of the Hebrew cosmogony to the facts of geology. But after rediscussing the measurements and readjusting the assumptions so as to reduce the time estimates in every reasonable way—and perhaps in some that were not so reasonable—they were still unable to compress the chapters of geologic history between the narrow covers of physical limitation; and there the matter rests for the present.

The rocks which were formed as sediments show many traces of rhythm. Some are composed of layers, thin as paper, which alternate in color, so that when broken across they exhibit delicate banding. In the time of their making there was a periodic change in the character of the mud that settled from the water. Others are banded on a larger scale; and there are also bandings of texture where the color is uniform. Many formations are divided into separate strata, as though the process of accretion had been periodically interrupted. Series of hard strata are often separated by films or thin layers of softer material. Strata of two kinds are sometimes seen to alternate through many repetitions. Borings in the delta of the Mississippi show soils and remains of trees at many levels, alternating with river silts. The rock series in which coal occurs are monotonous repetitions of shale and sandstone. Belgian geologists have been so impressed by the recurrence of short sequences of strata that they have based an elaborate system of rock notation upon it.

Passing to still greater units, the large aggregates of strata sometimes called systems show in many cases a regular sequence, which Newberry called a 'circle of deposition.' When complete, it comprises a sandstone or conglomerate, at base, then shale, limestone, shale and sandstone. This sequence is explained as the result of the gradual encroachment, or transgression, as it is called, of the sea over the land and its subsequent recession.

In certain bogs of Scandinavia deep accumulations of peat are traversed horizontally by layers including tree stumps in such way as to indicate that the ground has been alternately covered by forest and boggy moss. The broad glaciers of the Ice age grew alternately smaller and larger—or else were repeatedly dissipated and reformed—and their final waning was char-

acterized by a series of halts or partial re-advances, recorded in concentric belts of ice-brought drift. Of these belts, called moraines of recession, Taylor enumerates seventeen in a single system.

In explanation of these and other repetitive series incorporated in the structure of the earth's crust, a variety of rhythmic causes have been adduced; and mention will be made of the more important, beginning with those which have the character of original rhythms.

A river flowing through its delta clogs its channel with sediment and from time to time shifts its course to a new line, reaching the sea by a new mouth. Such changes interrupt and vary sedimentation in neighboring parts of the sea. Storms of rain make floods, and each flood may cause a separate stratum of sediment. Storms of wind give destructive force to the waves that beat the shore, and each storm may cause the deposit of an individual layer of sediment. Varying winds may drive currents this way and that, causing alternations in sedimentation.

To explain the forest beds buried in the Mississippi silts it has been suggested that the soft deposits of the delta from time to time settled and spread out under their own weight. Various alternations of strata, and epecially those of the coal measures, have been ascribed to successive local subsidences of the earth's crust, caused by the addition of loads of deposit. It has been suggested also that land undergoing erosion may rise up from time to time because relieved of load, and the character of sediment might be changed by such rising. Subterranean forces, of whatever origin, seemingly slumber while strains are accumulating, and then become suddenly manifest in dislocations and eruptions, and such catastrophes affect sedimentation.

A more general rhythm has been ascribed to the tidal retardation of rotation and the resulting change of the earth's form. If the body of the earth has a rather high rigidity, we should expect that it would for a time resist the tendency to become more nearly spherical, while the water of the ocean would accommodate itself to the changing conditions of equilibrium by seeking the higher latitudes. Eventually, however, the solid earth would yield to the strain and its figure become adjusted to the slower rotation, and then the mobile water would return. Thus would be caused periodic transgressions by the sea, occurring alternately in high and low latitudes.

Another general rhythm has been recently suggested by Chamberlin in connection with the hypothesis that secular variations of climate are chiefly due to variations of the quantity of carbon dioxide in the atmosphere.* The system of interdependent factors he works out is too complex for presentation at this time, and I must content myself with saying that his explanation of the moraines of recession involves the interaction of a peculiar atmospheric condition with a condition of glaciation, each condition tending to aggravate the other, until the cumulative results brought about a reaction and the climatic pendulum swung in the opposite direction. With each successive oscillation the momentum was less, and an equilibrium was finally reached.

Few of these original rhythms have been used in computations of geologic time, and it is not believed that they have any positive value for that purpose. Nevertheless, account must be taken of them, because they compete with imposed rhythms for the explanation of many phenomena, and the imposed rhythms, wherever established, yield estimates of time.

The tidal period, or the half of the lunar

* An attempt to frame a working hypothesis of the cause of glacial periods on an atmospheric basis. *Journ. Geol.*, Vol. VII., 1899.

day, is the shortest imposed rhythm appealed to in the explanation of the features of sedimentation. It is quite conceivable that the bottom of a quiet bay may receive at each tide a thin deposit of mud which could be distinguished in the resulting rock as a papery layer or lamina. If one could in some way identify a rock thus formed, he might learn how many half-days its making required by counting its laminæ, just as the years of a tree's age are learned by counting its rings of growth.

The next imposed rhythm of geologic importance is the year. There are rivers, like the Nile, having but one notable flood in each year, and so depositing annual layers of sediment on their alluvial plains and on the sea beds near their mouths. Where oceanic currents are annually reversed by monsoons, sedimentation may be regularly varied, or interrupted, once a year. Streams from a glacier cease to run in winter, and this annual interruption may give a definite structure to resulting deposits. It is therefore probable that some of the laminæ or strata of rocks represent years, but the circumstances are rarely such that the investigator can bar out the possibility that part of the markings or separations were caused by original rhythms of unknown period.

The number of rhythms existing in the solar system is very large, but there are only two, in addition to the two just mentioned, which seem competent to write themselves in a legible way in the geologic record. These are the rhythms of precession and eccentricity.

Because the earth's orbit is not quite circular and the sun's position is a little out of the center, or eccentric, the two hemispheres into which the earth is divided by the equator do not receive their heat in the same way. The northern summer, or the period during which the northern hemisphere is inclined toward the sun, occurs when the earth is farthest from the sun, and the northern winter occurs when the earth is nearest to the sun, or in that part of the orbit called perihelion. These relations are exactly reversed for the southern hemisphere. The general effect of this is that the southern summer is hotter than the northern, and the southern winter is colder than the northern. In the southern part of the planet there is more contrast between summer and winter than in the northern. The sun sends to each half the same total quantity of heat in the course of a year, but the difference in distribution makes the climates different. The physics of the atmosphere is so intricate a subject that meteorologists are not fully agreed as to the theoretic consequences of these differences of solar heating, but it is generally believed that they are important, involving differences in the force of the winds, in the velocity and course of ocean currents, in vegetation, and in the extent of glaciers.

Now, the point of interest in the present connection is that the astronomic relations which occasion these peculiarities are not constant, but undergo a slow periodic change. The relation of the seasons to the orbit is gradually shifting, so that each season in turn coincides with the perihelion; and the climatic peculiarities of the two hemispheres, so far as they depend on planetary motions, are periodically reversed. The time in which the cycle of change is completed, or the period of the rhythm, is not always the same, but averages 21,000 years. It is commonly called the precessional period.*

Assuming that the climates of many parts of the earth are subject to a secular cycle, with contrasted phases every 10,500

* Strictly speaking, 21,000 years is the period of the precession of the equinoxes as referred to perihelion; but the perihelion is itself in motion. As referred to a fixed star the precession of the equinoxes has an average period of about 25,700 years.

years, we should expect to find records of the cycle in the sediments. A moist climate would tend to leach the calcareous matter from the rock, leaving an earthy soil behind, and in a succeeding drier climate the soil would be carried away; and thus the adjacent ocean would receive first calcareous and then earthy sediments. The increase of glaciers in one hemisphere would not only modify adjacent sediments directly, but, by adding matter on that side would make a small difference in the position of the earth's center of gravity. The ocean would move somewhat toward the weighted hemisphere, encroaching on some coasts and drawing down on others; and even a small change of that sort would modify the conditions of erosion and deposition to an appreciable extent in many localities.

Blytt ascribed to this astronomic cause the alternations of bog and forest in Scandinavia, as well as other sedimentary rhythms observed in Europe; and it has seemed to me competent to account for certain alternations of strata in the Cretaceous formations of Colorado. Croll used it to explain interglacial epochs, and Taylor has recently applied it to the moraines of recession.

The remaining astronomic rhythm of geologic import is the variation of eccentricity. At the present time our greatest distance from the sun exceeds our least distance by its thirtieth part, but the difference is not usually so small as this. It may increase to the seventh part of the whole distance, and it may fall to zero. Between these limits it fluctuates in a somewhat irregular way, in which the property of periodicity is not conspicuous. The effect of its fluctuation is inseparable from the precessional effect, and is related to it as a modifying condition. When the eccentricity is large the precessional rhythm is emphasized; when it is small the precessional effect is weak.

The variation of eccentricity is connected with the most celebrated of all attempts to determine a limited portion of geologic time. In the elaboration of the theory of the Ice age which bears his name, Croll correlated two important epochs of glaciation with epochs of high eccentricity computed to have occurred about 100,000 and 210,000 years ago. As the analysis of the glacial history progresses, these correlations will eventually be established or disproved, and should they be established it is possible that similar correlations may be made between events far more remote.

The studies of these several rhythms, while they have led to the computation of various epochs and stages of geologic time, have not yet furnished an estimate either of the entire age of the earth or of any large part of it. Nevertheless, I believe that they may profitably be followed with that end in view.

The system of rock layers, great and small, constituting the record of sedimentation, may be compared to the scroll of a chronograph. The geologic scroll bears many separate lines, one for each district where rocks are well displayed, but these are not independent for they are labelled by fossils and by means of these labels can be arranged in proper relation. In each time line are little jogs—changes in kind of rock or breaks in continuity—and these jogs record contemporary events. A new mountain was uplifted, perhaps, on the neighboring continent, or an old uplift received a new impulse. Through what Davis calls stream piracy a river gained or lost the drainage of a tract of country. Escaping lava threw a dam across the course of a stream, or some Krakatoa strewed ashes over the land and gave the rivers a new material to work on. The jogs may be faint or strong, many or few, and for long distances the lines may run smooth and straight; but so long as the

jogs are irregular they give no clue to time. Here and there, however, the even line will betray a regularly recurring indentation or undulation, reflecting a rhythm and possibly significant of a remote pendulum whose rate of vibration is known. If it can be traced to such a pendulum there will result a determination of the rate at which the chronograph scroll moved when that part of the record was made; and a moderate number of such determinations, if well distributed, will convert the whole scroll into a definite time scale.

In other words, if a sufficient number of the rhythms embodied in strata can be identified with particular imposed rhythms, the rates of sedimentation under different circumstances and at different times will become known, and eventually so many parts of geologic time will have become subject to direct calculation that the intervals can be rationally bridged over by the aid of time ratios.

For this purpose there is only one of the imposed rhythms of practical value, namely, the processional; but that one is, in my judgment, of high value. The tidal rhythm can not be expected to characterize any thick formation. The annual is liable to confusion with a variety of original rhythms, especially those connected with storms. The rhythm of eccentricity, being theoretically expressed only as an accentuation of the precessional, can not ordinarily be distinguished from it. But none of these qualifications apply to the precessional. It is not liable to confusion with the tidal and annual because its period is so much longer, being more than 2000 times that of the annual. It has an eminently practical and convenient magnitude, in that its physical manifestation is well above the microscopic plane, and yet not so large as to prevent the frequent bringing of several examples into a single view. It is also practically regular in period, rarely deviating from the average length by more than the tenth part.

From the greater number of original rhythms it is distinguished, just as from the annual and tidal, by magnitude. The practical geologist would never confuse the deposit occasioned by a single storm, for example, with the sediments accumulated during an astronomic cycle of 20,000 years. But there are other original rhythms, known or surmised, which might have magnitudes of the same general order, and to discriminate the precessional from these it is necessary to employ other characters. Such characters are found in its regularity or evenness of period, and in its practical perpetuity. The diversion of the mouth of a great river such as the Hoang Ho or the Mississippi, might recur only after long intervals; but from what we know of the behavior of smaller streams we may be sure that such events would be very irregular in time as well as in other ways. The intervals between volcanic eruptions at a particular vent or in a particular district may at times amount to thousands of years, but their irregularity is a characteristic feature. The same is true of the recurrent uplifts by which mountains grow, so far as we may judge them by the related phenomena of earthquakes; and the same category would seem to hold also the theoretically recurrent collapse of the globe under the strains arising from the slowing of rotation. The carbon-dioxide rhythm, know as yet only in the field of hypothesis, is hypothetically a running-down oscillation, like the lessening sway of the cradle when the push is no longer given.

But the precessional motion pulses steadily on through the ages, like the swing of a frictionless pendulum. Its throb may or may not be caught by the geologic process which obtains in a particular province and in a particular era, but whenever the conditions are favorable and the connection is

made, the record should reflect the persistence and the regularity of the inciting rhythm.

The search of the rocks for records of the ticks of the precessional clock is an out-of-door work. Pursued as a closet study it could have no satisfactory outcome, because the printed descriptions of rock sequences are not sufficiently complete for the purpose; and the closet study of geology is peculiarly exposed to the perils of hobby-riding. A student of the time problem cannot be sure of a persistent, equable sedimentary rhythm without direct observation of the characters of the repeated layers. He needs to avail himself of every opportunity to study the series in its horizontal extent, and he should view the local problem of original *versus* imposed rhythm with the aid of all the light which the field evidence can cast on the conditions of sedimentation.

Neither do I think of rhythm seeking as a pursuit to absorb the whole time and energy of an individual and be followed steadily to a conclusion; but hope rather that it may receive the incidental and occasional attention of many of my colleagues of the hammer, as other errands lead them among cliffs of bedded rocks. If my suggestion should succeed in adding a working hypothesis or point of view to the equipment of field geologists, I should feel that the search had been begun in the most promising and advantageous manner. For not only would the subject of rhythms and their interpretations be advanced by reactions from multifarious individual experiences, but the stimulus of another hypothesis would lead to the discovery of unexpected meanings in stratigraphic detail.

It is one of the fortunate qualities of scientific research that its incidental and unanticipated results are not infrequently of equal or even greater value than those directly sought. Indeed, if it were not so there would be no utilitarian harvest from the cultivation of the field of pure science.

In advocating the adoption of a new point of view from which to peer into the mysterious past, I would not be understood to advise the abandonment of old standpoints, but rather to emulate the surveyor, who makes measurement to inaccessible points by means of bearings from different sides. Every independent bearing on the earth's beginning is a check on other bearings, and it is through the study of discrepancies that we are to discover the refractions by which our lines of sight are warped and twisted. The three principal lines we have now projected into the abyss of time miss one another altogether, so that there is no point of intersection. If any of them is straight, both the others are hopelessly crooked. If we would succeed we should not only take new bearings from each discovered point of vantage, but strive in every way to discover the sources of error in the bearings we have already attempted.

G. K. Gilbert.

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*THE EIGHTH GROUP OF THE PERIODIC SYSTEM AND SOME OF ITS PROBLEMS.**

I.

In the early work of Newlands and of Mendeléeff, which subsequently developed into the periodic law, a serious difficulty was met with in dealing with iron, cobalt, nickel, and the metals of the platinum group. In Newlands' modified statement of his law of octaves he says: "The numbers of analogous elements, *when not consecutive*, differ by seven or by some multiple of seven." Thus we find him grouping† cobalt and nickel under a single number; so rhodium and ruthenium; so also platinum and iridium. Cobalt, nickel, palladium, plati-

*Address by the Vice-President and Chairman of Section C., American Association for the Advancement of Science, June, 1900.

† *Chem. News*, 13, 130 (1866).